Developments and Application of Lightweight Steel Components in Housing

Andrew S. Zakrzewski

DEVELOPMENTS AND APPLICATION

OF LIGHTWEIGHT STEEL COMPONENTS

IN HOUSING

by

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SUMMARY

DOFASCO have during the last 4 years worked on the development of panelized housing systems as well as steel components for "stick-built" houses.

This paper briefly describes the company's development in the following areas:

- Joining Methods
- Structural characteristics of steel/gypsum and steel/plywood panels
- Vibrational response and accoustical characteristics of some light gauge steel floor decks

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INTRODUCTION

At the outset, I must state that this paper is not a scientific paper nor even an engineering report. It is a brief account of some engineering problems one company has encountered when trying to introduce structural steel components into housing.

We have less than 4 years experience in this particular field, so I seriously considered to wait for at least another 6 years before writing a paper on this subject. But then I changed my mind: this is a relatively new field, and much research and development is urgently needed. Perhaps by briefly describing some of our problems and preliminary tests, I will create more interest among Applied Scientists and Development Engineers and, at the same time, obtain some advice from those who have already done work in this field.

Shelter represents for an average family the largest single purchase in their life; mortgage, taxes and upkeep absorb as much as 1/4 of their income. And yet steel, the most universal metal has barely started to be used as structural or cladding material in houses.

Until recently timber was relatively inexpensive and easily available. Wood has reasonably good insulating properties and can be easily cut to size on site and easily joined. The same applies to bricks. But prices of lumber climbs faster than

INTRODUCTION (Continued)

those of steel and I do not have to tell you how much the brickwork costs.

Because of high cost and shortage of skilled on-site labour, a steadily growing percentage of house building activity is being transferred to plants. But steel has advantages over lumber when it comes to prefabricated components: the raw materials require less space, the material is more homogenous and not subjected to warpage, etc. The close tolerances to which steel components can be manufactured means that, provided the design is well thought out, the on-site erection times can be reduced.

Housing is the last frontier not yet conquered by steel. It will not be conquered overnight. Many companies - including ours - were overenthusiastic and over-optimistic. But I would not be surprised if steel replaces say 50% of wood in house framing during the next decade.

Wood cannot simply be "replaced" by steel: in order to be competitive we will have to adapt the design to steel's properties, ie. to change spans, shapes, joining methods, insulation, etc. Most steel members will be made from light gauge steel in the range of 16 ga. to 30 ga. The use of steel is not restricted to framing: We have already used steel panels to replace concrete basement walls and steel plates to replace concrete

INTRODUCTION (Continued)

foundation footings. We have used steel panels as ground floor decks, and their embossed, painted side as finished basement ceiling. We have used prepainted steel siding. We have built central service core structures from steel. Galvanized steel roofs are very popular in some European countries.

Figures 1 and 2 depict townhouses Dominion Foundries & Steel Co. (Dofasco) of Hamilton, Ontario has built and erected during 1971/1972, using a modified British "IBIS" system. This post-and-beam system uses prefabricated panels for walls and floors.

During the second half of 1972 and first half of this year, we have developed a much more economical panel system consisting of prefabricated load bearing walls and decks. An experimental "house rig" (corresponding to about 40% of a full townhouse) is shown in Figures 3 and 4.

The few examples of problems we encountered and our attempts to solve them show, I think, the necessity of close collaboration between the designers, the stress specialists, the test engineers, and inventive production engineers. Some of the components mentioned in the text or shown on the enclosed photographs are covered by patents or patent applications.

JOINING

Joining of components - whether in plant or on site - is the most labour consuming aspect of house framing.

JOINING (Continued)

One of the greatest assets of conventional wood framing of houses is the ease with which the components can be cut to size and joined not only in a plant but also on site: all one needs is a power saw, a hammer and nails. In order to be competitive, the suppliers of steel components are adapting old and developing new technologies, but these developments are still in an early stage and much remains to be done.

Steel studs and joists can be cut to size on site but it should be seldom necessary to do so, because by using steel we are eliminating the problems of warpage and shrinkage and consequently can provide components manufactured to much closer tolerances. This "exactness" is potentially the greatest asset of using metals in the building of houses. It also puts new demands upon the ingenuity of the designers to develop joints and joining method which will reduce the labour cost, and particularly cost of erection.

Let's briefly review the "state of art" of joining metal housing components.

(i) Self-Drilling Screws

These screws, commerically available for only a few years, make it possible to join metal-to-metal or non-metal to metal components in one operation, with an access from

(i) Self-Drilling Screws (Continued)

one side only. If a correct type of screw is used, even a plate can be drilled through, but the screws are particularly useful in connecting light gauge steel components. The metal-to-metal connections do not differ from those obtained by means of ordinary sheet metal screws, but much more must be learned about the permissible loads, particularly shear loads, when materials such as plywood and gypsum board are to be joined to sheet metal components.

(ii) Welding and Spot Welding

Most sheet steel housing components are galvanized. Welds on galvanized steel have to be protected against corrosion, an operation that adds to the cost of joining. Automotive companies have studied the problems of spot welding of galvanized steel extensively, but more information is required for structural components. The use of resistance spot welders is limited to in-plant applications and to cases where the two electrodes can reach from both sides.

Innert gas welding (e.g. MIG welding) is very fast; innert gas spot welding is even faster and, contrary to resistance spot welding, can be applied from one side and can be used on erection site.

(ii) Welding and Spot Welding (Continued)

The quality of welds deteriorates if there is an appreciable gap between the two surfaces to be spot welded. In the case of non-horizontal surfaces, the molten metal has a tendency to flow away from the area to be welded. There are too many variables of this kind to obtain really reliable spot welds, and more research is required. (See preliminary test specimens Figure 5).

(iii) Adhesives

Adhesives are being used in housing in an increasing degree, but the use of adhesives under field conditions still requires more research: the steel may not be degreased, the ambient temperature may vary considerably, the components might be wet, and yet we expect the adhesives to work. A few screws or spiral nails might be used to secure the proper location and good initial contact of components to be bonded.

We have successfully bonded plywood to steel joist frames (see Figure 6) but used screws as well. As expected, the addition of an adhesive did not change the stiffness of the deck, but I suspect that the stiffness of a deck without adhesive would decline with time, because the screws would become loose. We plan to check this point.

(iii) Adhesives (Continued)

Some manufacturers use the adhesive in decks to eliminate the "squeaking" of floors.

Most adhesives are weak in shear, particularly in shear impact. This does not apply to adhesives that remain always "tacky", but these allow the components to creep.

(iv) Rivetting

Because the one sided spot welding of galvanized steel sheets is not yet reliable, rivetting in most heavily loaded areas might be considered as a "security measure". Car frame components are joined by means of MIG welding and where the shear forces are very high with a few heavy rivets. Because rivetting requires two sequential operations, punching (or drilling) and rivetting , it is not as simple as welding, particularly under "on site" conditions. Various kinds of pop rivets are available for joining of components accessible from one side only, but the shear strength of such rivets is generally very poor. More research in this area and development of new techniques and new types of fasteners is required.

(v) Other Joining Methods

The simplest method of joining sheet metal components is to "build in" the joining component into them: by

(v) Other Joining Methods (Continued)

pre-punching slots into one component and protruding tabs into the other, the two components can be joined by inserting the tab into the slot and bending it over. This kind of joint is presently being used in some steel framing systems for location purposes. A great deal of development remains to be done in testing various configuration of such locating systems. Perhaps a combination of such systems and adhesives will render a quick and inexpensive means of connecting housing framing components.

STRUCTURAL CHARACTERISTICS OF COMPOSITE FLOOR DECK

Steel Joist Plywood Sheathing

This combination becomes increasingly popular in houses as a replacement for a wood joist plywood sheathing floor deck.

In our first test series we have selected a high modulus joist section, $I_{xx} = 18.328\ \text{inch}^4$ (Figure 7) which would be suitable for up to 24 foot span decks. The governing factor in the design of decks is usually the stiffness and not the strength, because the building code specifies a maximum permissible deflection (e.g. the Canadian Building Code specifies that

$$\frac{\text{maximum deflection}}{\text{joist span}} \leq \frac{1}{360}$$

Steel Joist Plywood Sheathing (Continued)

The joists were arranged at 24 inch centers and the 4 by 8 foot plywood sheets were 3/4 inch thick. The deck span was either 23 feet or 16 feet.

The steel frameconsisting of steel joists and headers (see figure 8) was tested under a UDL and the maximum deflections were recorded. The frame was then sheathed with plywood, and again maximum deflections were recorded under various UDL's. The tests have shown that for identical UDL the deflections were 14 percent smaller in the latter case. Floor decks are, of course, never loaded uniformly, the behaviour of decks under point loads is therefore of great importance. We have carried out tests to determine the transfer of point loads onto several adjacent joists. As could be expected, plywood alone does not spread the load very effectively. We found for instance, that if a point load applied directly over a joist resulted in a deflection "y", the deflection of the adjacent joist, at the same distance from the deck support amounted to about .30y. Connection of joist flanges with steel straps or with shallow profiles does not appreciably stiffen the deck structure, because the joists have a very low torsional resistance and consequently the whole steel system twists. Diagonal bridging of joists - frequently used in wood construction (see reference 2) - is effective in steel, but not any cheaper than connecting adjacent joists by a full pan-shaped connector (see figure 9) In order to avoid redundancy of joist as well as in order to facilitate installation of decks and of services, Steel Joist Plywood Sheathing (Continued)

We have adapted a design which leaves a gap between two adjacent decks. The same pan-shaped connector as mentioned above can be used to join the adjacent decks. (See Figure 10). General arrangement of two of several tests are shown in Figures 11 and 12. Some test results are shown in Figure 13.

LOAD CARRYING CAPACITY OF WALLS

Load Bearing Steel Studs, Sheathed with Gypsum

Walls of this kind usually consist of studs, attached on the bottom to a "sole plate" and on the top to a "head plate", thus forming a steel frame. The frame is usually sheathed either on one or on both sides with gypsum board. The studs are braced by either continuous or intermittent attachments to the sheathing material thus forming a "composite wall." The maximum allowable spacing of intermittent attachments is specified in the "Light gauge cold-formed steel design manual", issued by the American Iron and Steel Institute (A.I.S.I.)

We have carried out a series of tests to check the restraint properties of gypsum. First, stud compression tests were carried out (see Figures 14 and 15) to determine the buckling load and its increase by restraining of studs twisting. It can be shown that the gypsum board does provide this restraint.

Load Bearing Steel Studs, Sheathed with Gypsum

A short section of an 8'8" high wall was then subjected to a compression test. The wall consisted of three 18 ga. C-shaped studs, sheathed on both sides with 1/2" thick sheetrock fire-code "C" gypsum board. (See Figures 16, 17 and 18).

Load capacity of studs supported with gypsum increased by about 70% as compared with unrestrained studs. The test results indicate that the two gypsum boards prevent twisting of studs and, to a smaller degree, reduce the bending stresses in the studs.

The failure occurred due to buckling of the stud flange caused by high compressive stresses (See Figures 19 and 20).

Finally, we have tested a 14 foot long, 9 foot high wall panel (see Figure 21) under vertical UDL and horizontal load (which simulated the wind load). This last series of tests was carried out at McMaster University in Hamilton, Ontario.

The monitoring system consisted of twelve dial gauges, locations of which are shown in Figure 22 and ten strain gauges as shown in Figure 23.

The loading was provided by hydraulic jacks controlled by manual pumps and associated load cells.

Load Bearing Steel Studs, Sheathed with Gypsum

The length of the specimen wall was equal to half the length of an actual common wall of a townhouse. Four series of tests were carried out, namely:

(i) Application of a small vertical load (dead load) and then application of a horizontal load, in increments, up to the double design load.

(ii) Application of vertical load only, in increments, up to the double design value.

(iii) Application of horizontal load up to 1.5 design load and of vertical load up to 1.3 design load.

(iv) Application of horizontal load up to 1.0 design load and vertical load up to 1.5 design load after cutting the crossbracing member (see Figure 24).

Test Results

Part (i) Stress level in the crossbracing shows that the studs and gypsum restrain more than 75% of the horizontalforce and that, consequently, the diagonal bracing is not required.

Test Results (Continued)

Part (ii) A comparison of the total vertical load with the readings of strain gauges located on one of the studs shows that almost 40% of the compression is carried by the gypsum board at double design load. Excellent recovery for the dial gauges and reasonably good recovery for the strain gauges was experienced.

Part (iii) Strain gauge #7 located on the only stud made from 16 ga. material, recorded the effects of both the vertical and horizontal loads. The maximum stress amounted to 7560 psi. Recovery after unloading was good.

Part (iv) After reaching the planned loads both the horizontal and the vertical loads were increased with the latter reaching 2.3 times the design load without a significant deterioration of the panel. Loads were not increased any further to avoid possible damage to the load cell and dial gauges.

Conclusions

(1) The panel proved to be overdesigned; it was decided that studs could be manufactured from 22 ga. steel.

Conclusions (Continued)

(2) In-plane and out-of-plane deflections were not excessive; the largest deflection was registered on dial #8, on trial (ii) and amounted to a little over 1/2".

(3) Stresses in the studs never exceeded 12,660 psi.

(4) Gypsum board carried a considerable amount of loads, including vertical compression loads.

EXPERIMENTAL PROVING OF STRUCTURAL DESIGN DETAILS

Steel Housing Structures

Like any other structures, the sheet metal structures are only as strong as their weakest point.

When competing with wood-made house structures, one must always bear in mind that steel is a less "forgiving" material than wood: dimensional errors in some of the components do not usually result in the same stress concentration in a wooden structure as they do in a steel structure . In particular, there exists a danger of overdesigning, of creating too stiff components or joints which increase stresses in weaker elements of the structure. Due to the continuous danger of local buckling, the light gauge structures must be even more carefully designed than the heavier steel structures.

Steel Housing Structures (Continued)

Calculation of parameters for even relatively simple sheet metal components (such as studs or joists) require a lot of time; determination of stresses in a complex structure by calculation would be hardly feasible.

We found that relatively simple tests carried out on an element, particularly, on a connector element would help to optimize the design.

I have selected two examples of such "designing by test". The first example shows the connection between a load bearing wall stud and a sole plate. For other design reasons the sole plate had an assymetrical shape and a satisfactory solution had to be found for transferring of compression forces from the studs into the sole plate. Figures 25, 26, 27 and 28 show two designs.

The second example has to do with the connection in a deck between joists and the head beam. Loading of the experimental deck in increments until crippling occurred has shown the mode of failure and lead to a redesign of the header beam as well as improvement in joining. (See Figures 29, 30 and 8).

VIBRATIONAL RESPONSE OF LIGHT GAUGE STEEL DECKS

Floor decks made from light gauge steel are a relatively new development. In one type of deck the wooden joists are replaced by roll-formed steel joists. In the other, the whole deck is made from sheet steel sections (e.g. Armco's 16" wide and 3" or 4" deep sections) which are then sheathed on the open side with plywood.

People are used to "walking and wood", and have done so for many centuries. Introduction of a new material is viewed with certain apprehension. In the case of floors, questions are asked about "springiness", "hardness", vibrations, accoustic qualities, etc. About 2 years ago our Company built as a pilot project of 66 townhouses. The houses did not have basements and consequently the washers and dryers were installed on the ground floor, on steel joist floor decks. Because of lack of space, front loading washers were selected and some of them vibrated excessively. Right away the supplier stated that the excessive vibrations were caused by the steel floors.

To disprove this statement, we had to build and test two decks: a typical wood deck and a steel joist deck. By operating the washing machine on both decks, we were able to prove that the washer vibrations were even worse on the wooden deck. After this experience we decided to learn more about what makes a deck satisfactory. According to some reports (reference 1) the judgment as to the "comfort" of a floor is highly subjective. If steel is to succeed in floors, some satisfactory, objective answers will have to be found. We plan to do some testing in this area and we hope that others will also do so.

VIBRATIONAL RESPONSE OF LIGHT GAUGE STEEL DECKS

Since the maximum deflection of housefloor decks is limited by building codes, and since additional stiffness costs money, the deflection of wooden and steel decks must be about equal. It follows that the vibration amplitude must be about equal. If the decks using steel or wood joists respectively are designed in such a manner that their span and their stiffness are identical, then the natural frequency of the respective joists will depend on two other parameters: the crossectional area of joists and the specific gravity of the materials. We found that the natural frequency of steel joists will be about 35% higher than that of wood joists.

Wood has of course better damping characteristics than steel, but whether it seriously affects the feeling of comfort remains to be seen.

We have carried out preliminary vibration tests on floors of a "house rig" which we built recently outside our R & D building. The floor decks are 18' long and 4' wide, have 10-3/4" high joists at 24" centers and are sheathed with 3/4" thick plywoods.

The test equipment consisted of an IRD, Model 330 Vibration Analyser and an oscillographic recorder.

VIBRATIONAL RESPONSE OF LIGHT GAUGE STEEL DECKS

The system's frequency response is shown in Figure 31. We knew that the 1200 cpm frequency was that of the steel joists. At first we could not figure out what caused the high amplitude 100 cpm frequency which, as you can see from the Figure 31 was highly damped. It took some time until we found that this is the natural frequency of the joist flange, subjected to bending. Figure 32 explains what happened: the joist was not properly rolled and the angle between the flange and the web was greater than 90°. At least we have learned a lesson: in order to obtain good floors one must specify the tolerances in such a manner that the above mentioned angle never exceeds 90°.

The vibrational response of the floor to a single impact (dropping of 13.5 lbs load from 23 inches), filtered at the joists' natural frequency of 1200 cpm, is shown in Figure 33. The damping factor amounts to 0.03.

THE ACCOUSTIC CHARACTERISTICS OF FLOOR DECKS

The steel-framed townhouses we have built do not seem to be accoustically inferior to wood-framed townhouses. This is merely our opinion, because we have not yet made any instrumented tests. The excessive vibrations caused by the front-loading washing machines (as described in the previous paragraphs) did result in a high level of noise, but the noise might have been as intensive in a wood-framed house.

THE ACCOUSTIC CHARACTERISTICS OF FLOOR DECKS

Lately we had an opportunity to participate in the development of an experimental house using a number of steel components. The ground floor consisted of Armco steel panels as shown in Figure 34. Fear was expressed that this combination of hollow steel pans sheathed on top with plywood but with no additional protection on the bottom, will act as a resonance box.

In order to make a direct comparison between a typical wooden floor deck and a steel deck (for specification see Figure 35), we have erected two adjacent 4 feet high enclosures (see Figure 36), insulated their walls with fibreglass and covered them with the test decks. In order to compare the accoustic properties of test decks, one person (or persons) would enter the two enclosures while another person would walk on top of the decks, jump on them, etc. This admittedly rather crude and subjective assessment did nevertheless give us some idea about the level and quality of noise. The sound level beneath the top decks seemed to be about equal, but the steel deck's sound was more "tinny".

Insertion of fibreglas batts into the steel deck have markedly improved the sound absorbtion. In a further test we have covered both decks with a piece of carpet. The sound-damping value of the carpet was very pronounced. Surprisingly, the effect of the carpet was greater on the steel deck than on the wooden deck. We have recorded the sounds on a tape recorder.

THE ACCOUSTIC CHARACTERISTICS OF FLOOR DECKS

We have also attempted to eliminate the subjective factor from tests by measuring the noise level, using a model 2203 B. & K. precision sound level meter.

The results of this test are shown in Figure 37.

I doubt that the human comfort can be related to the decibel value above because some combinations of frequencies are more unpleasant to the ear than others.

CONCLUSIONS

It is quite possible that steel will replace during the next decade a good portion of wood as structural as well as cladding material in houses.

Different material and higher degree of prefabrication will require new design concepts which should be backed up by an extensive research and development effort.

A close collaboration between the scientists, designers and production engineers is called for.

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American Iron & Steel Institute, 1962

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Ali Siereg, International Textbook Company, 1969

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FIGURE 1

FIGURE 2

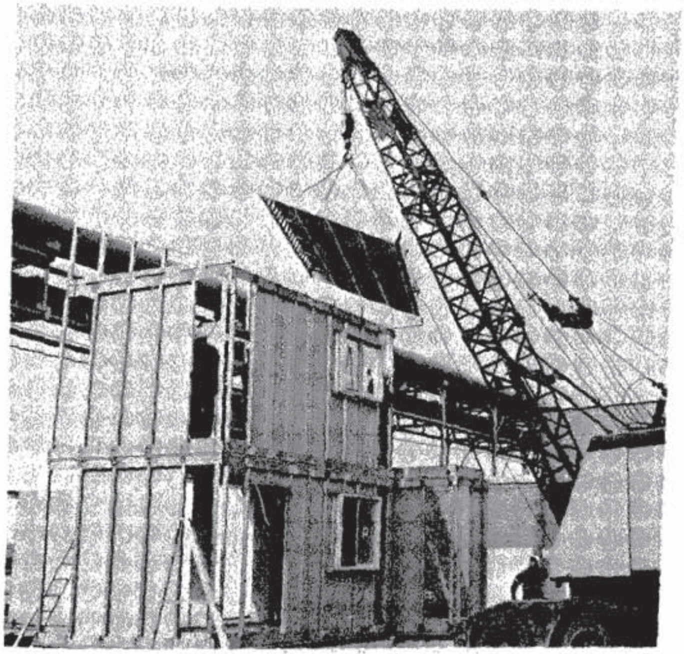


FIGURE 3

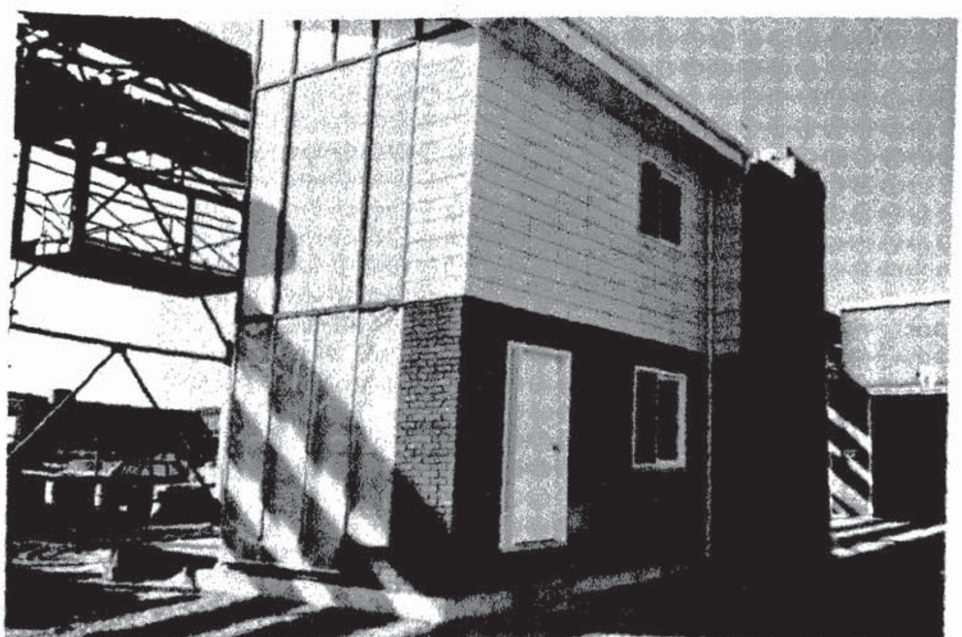


FIG. :

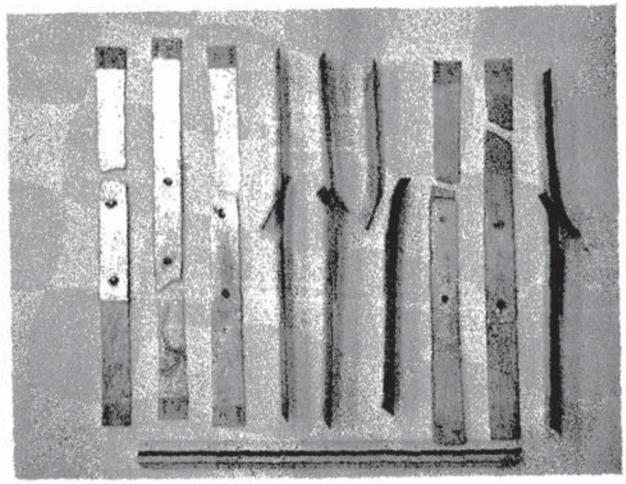


FIGURE 5

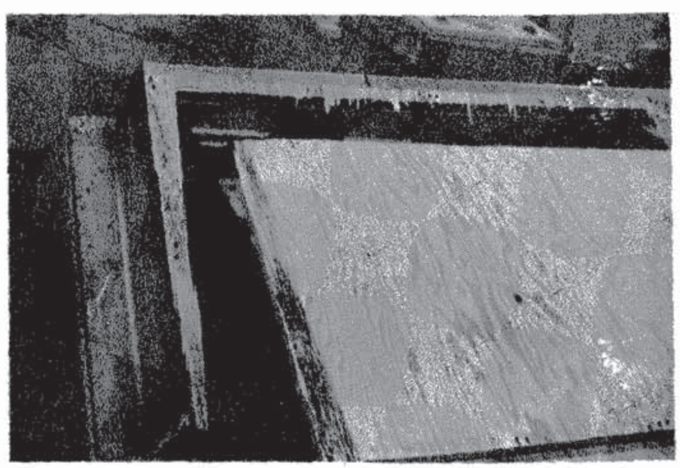


FIGURE 6

MATERIAL

0.0625" (16 GA)
CONTINUOUSLY GALVANIZED STRIP
ZINC @ 1-1/4 OZ./SQ.FT.
BASE STEEL TO ASTM 446/67B

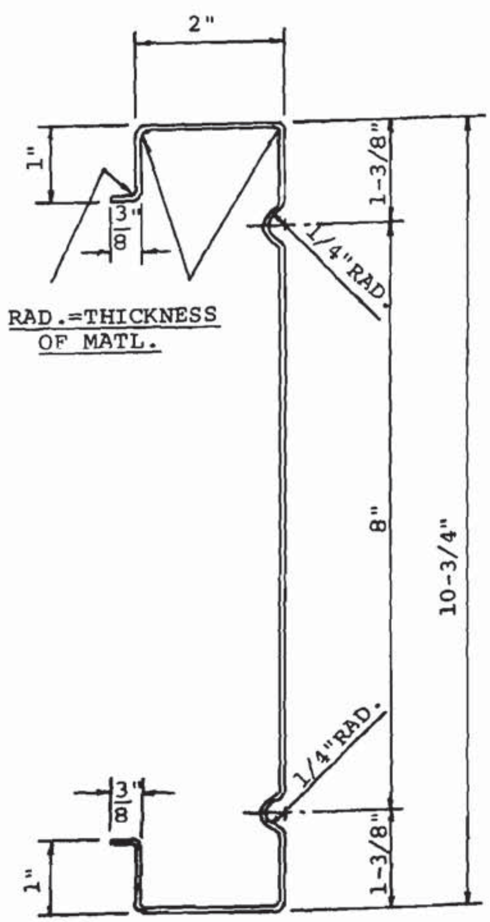


FIG. 7

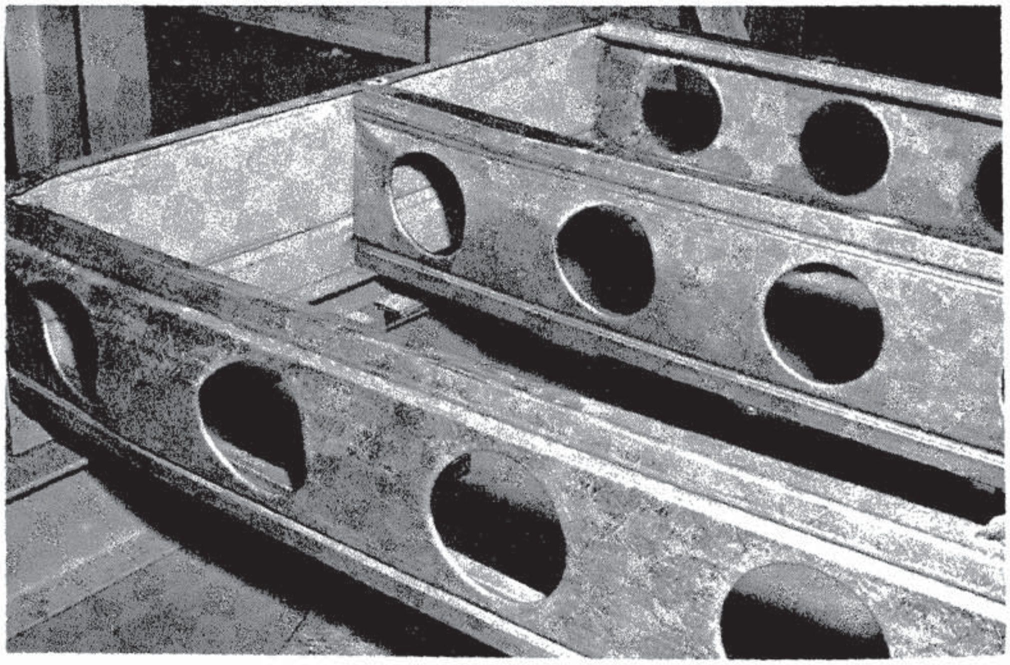


FIGURE 8

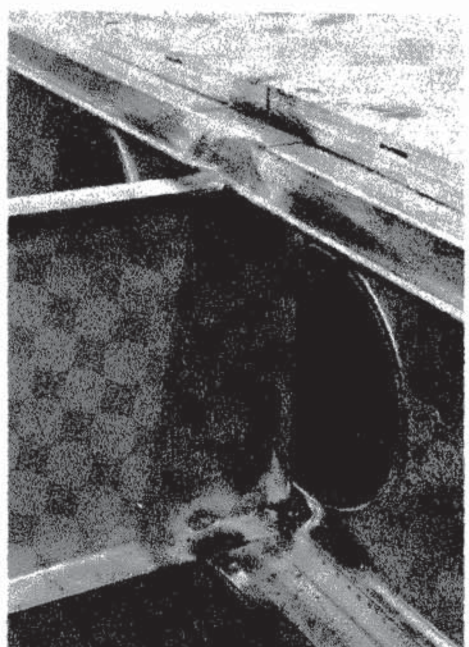


FIGURE 9

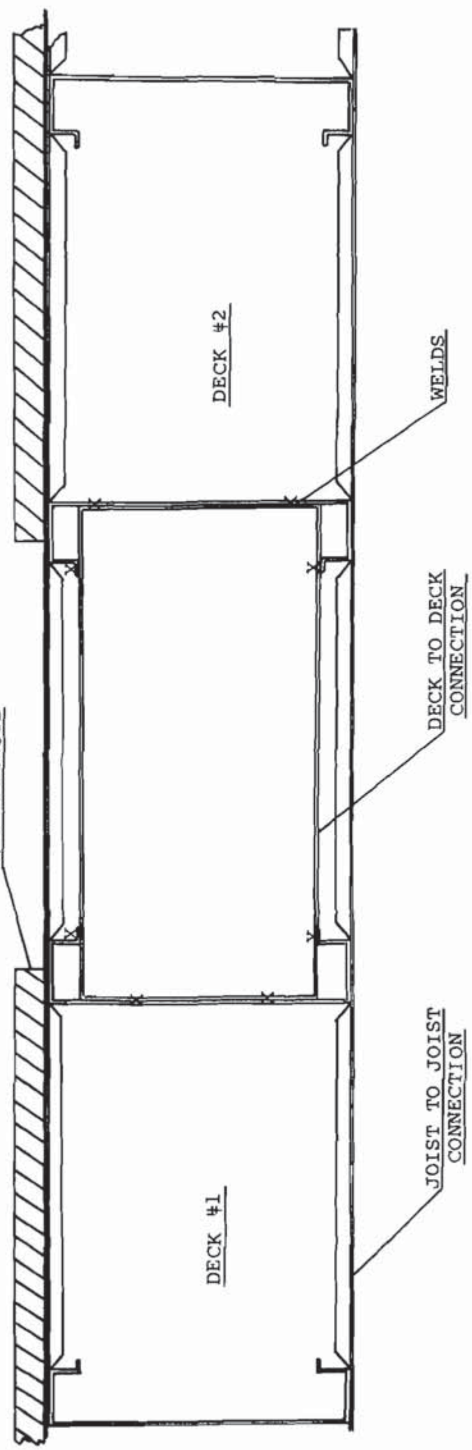

DECK #2
WELDS
DECK TO DECK
CONNECTION
3/4" PLYWOOD
JOIST TO JOIST
CONNECTION
DECK #1

FIGURE 10

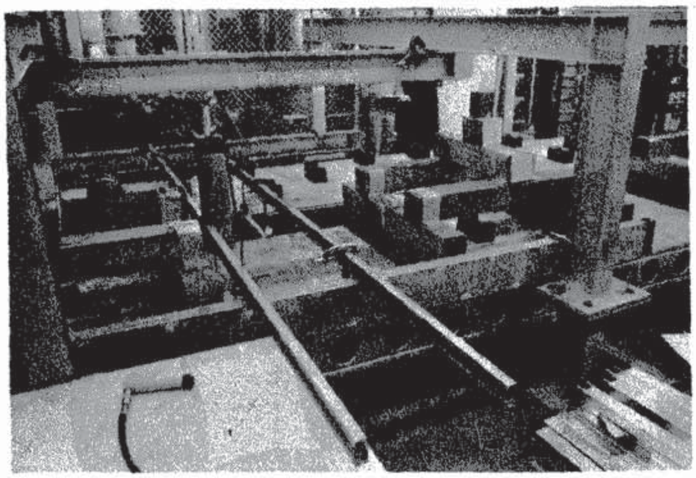


FIGURE 11

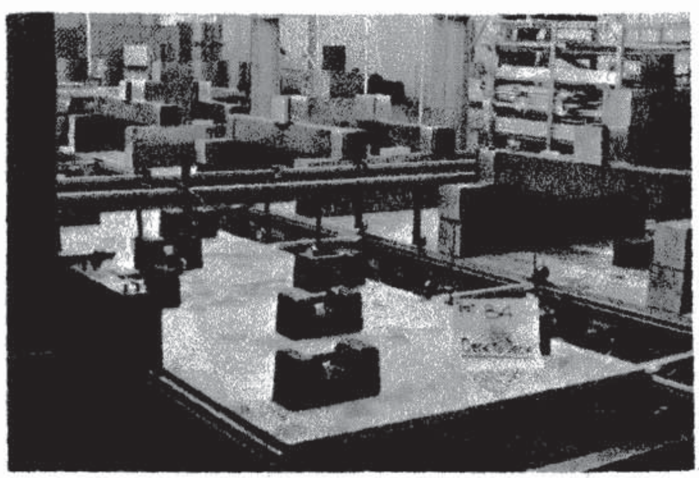


FIGURE 12

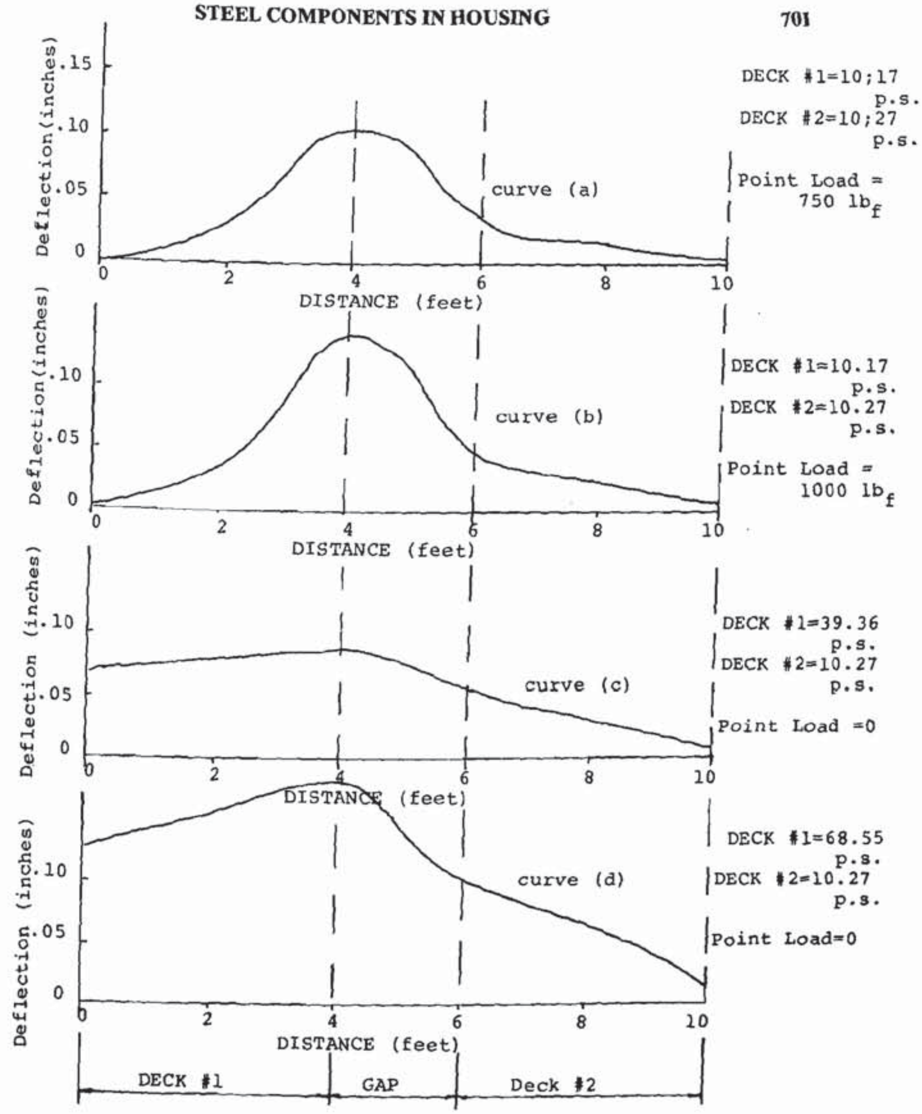

Deflection (inches)
.15
.10
.05
0
DISTANCE (feet)
0 2 4 6 8 10
curve (a)
DECK #1=10;17 p.s.
DECK #2=10;27 p.s.
Point Load = 750 lb_f
curve (b)
DECK #1=10.17 p.s.
DECK #2=10.27 p.s.
Point Load = 1000 lb_f
curve (c)
DECK #1=39.36 p.s.
DECK #2=10.27 p.s.
Point Load =0
curve (d)
DECK #1=68.55 p.s.
DECK #2=10.27 p.s.
Point Load=0
DECK #1
GAP
Deck #2

FIGURE 13

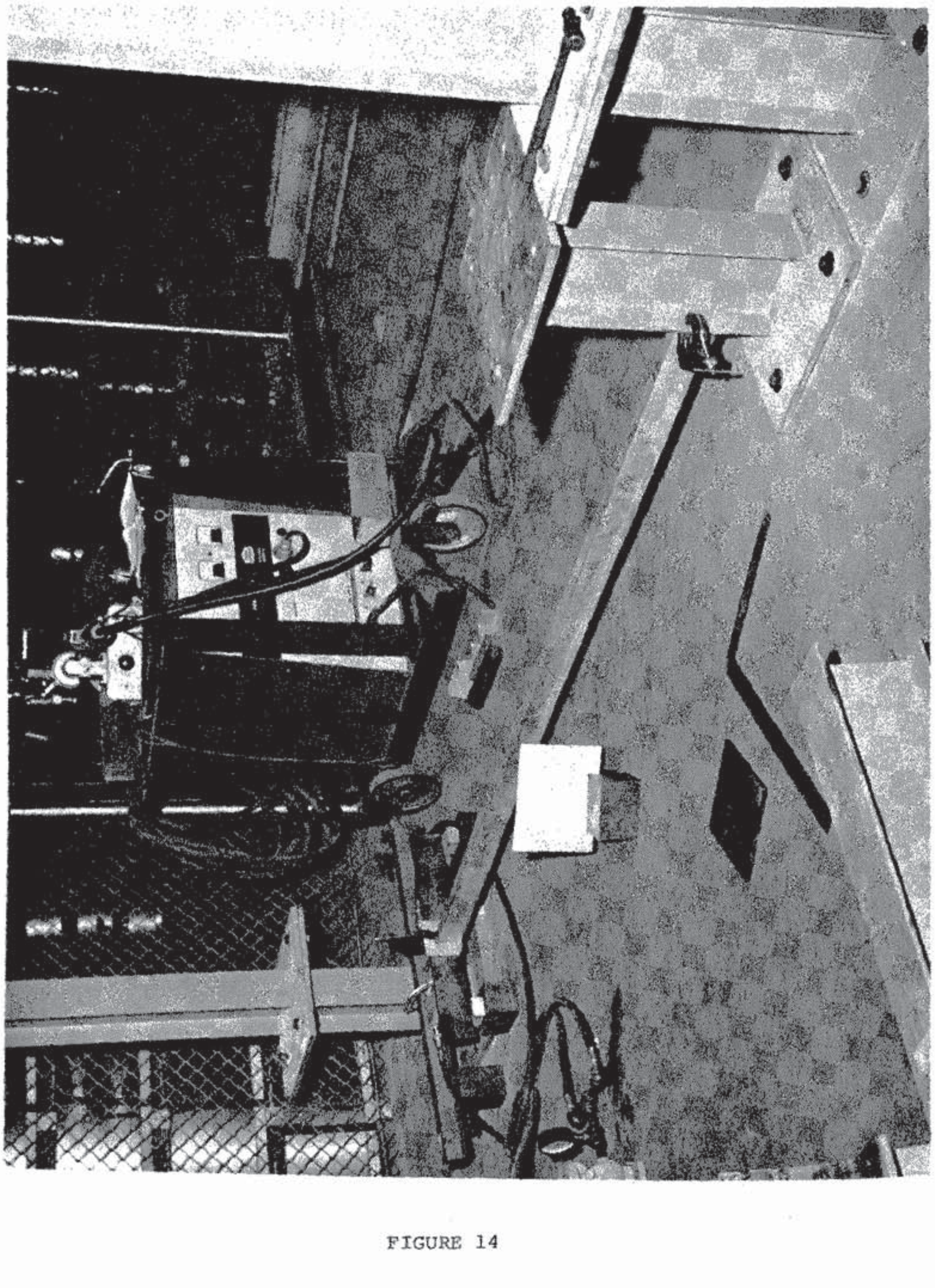


FIGURE 14

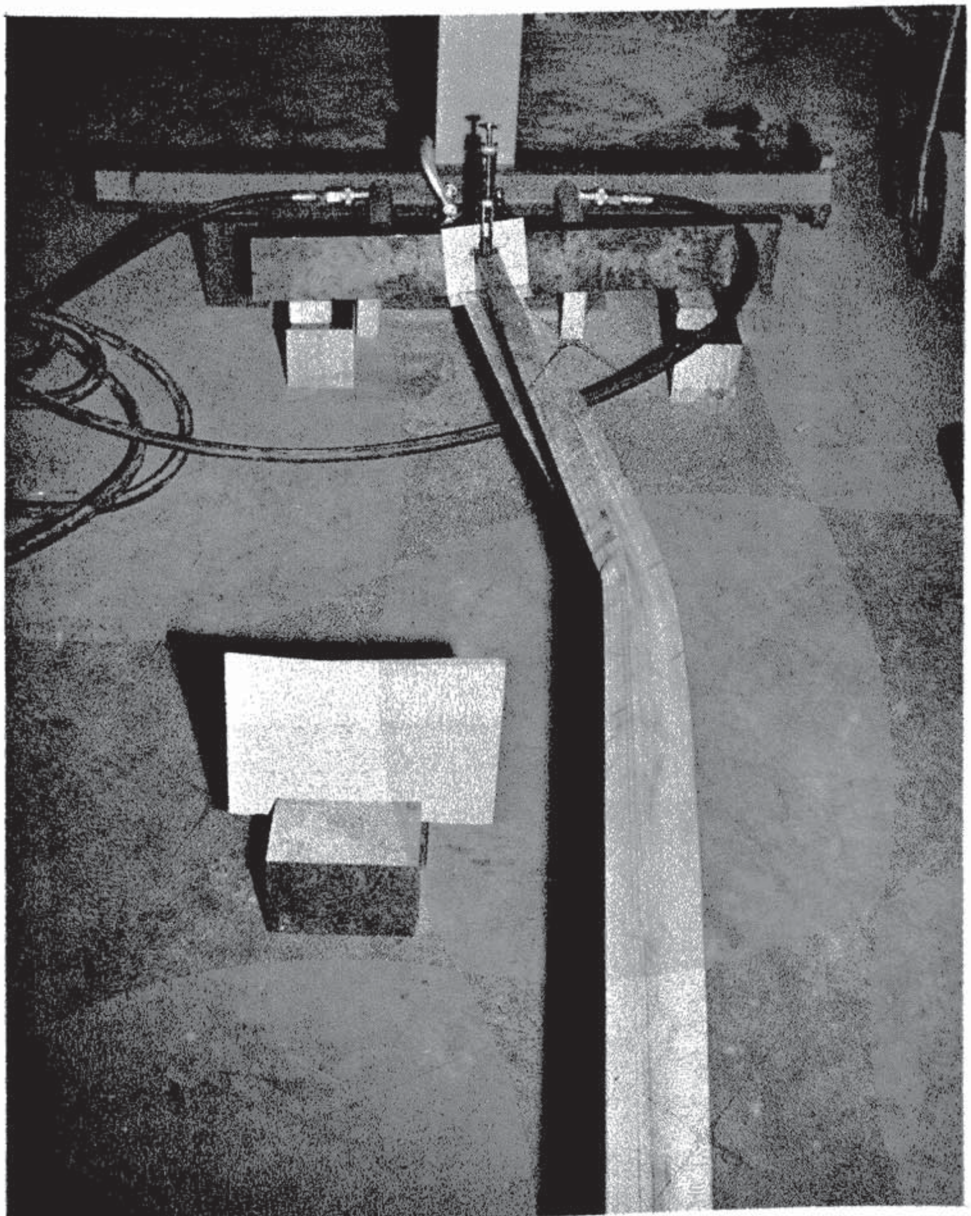


FIGURE 15

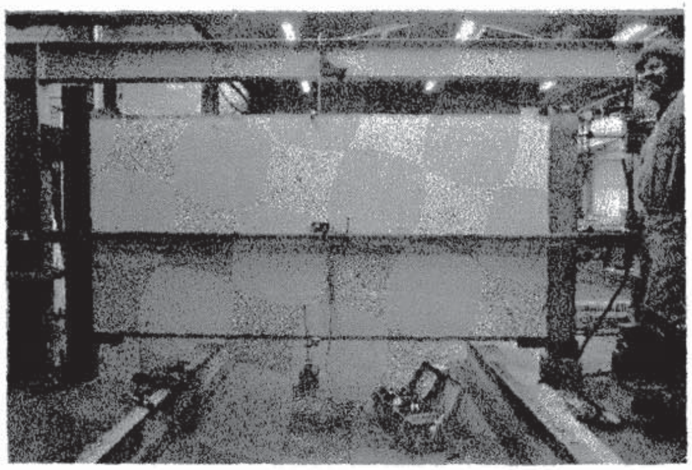


FIGURE 16

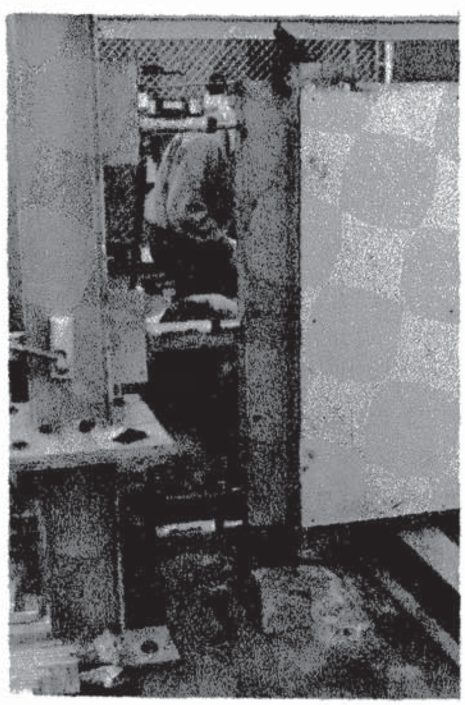
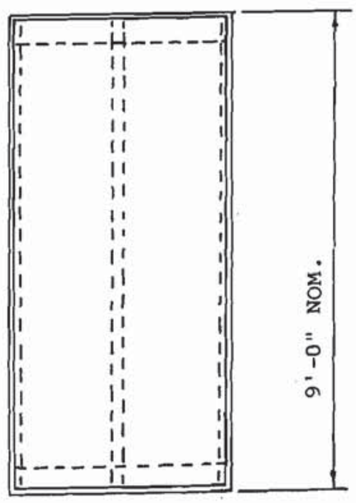
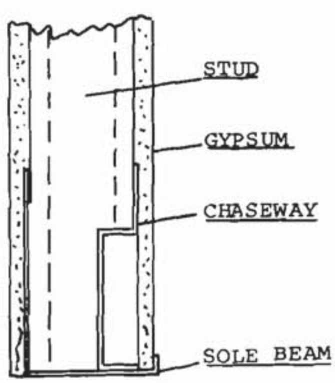


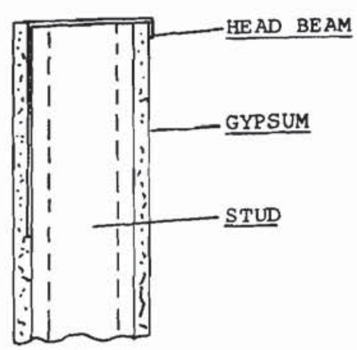
FIGURE 17



4'-0" NOM. WALL



SECTION AT BOTTOM
OF WALL



SECTION AT TOP
OF WALL

FIG. 18

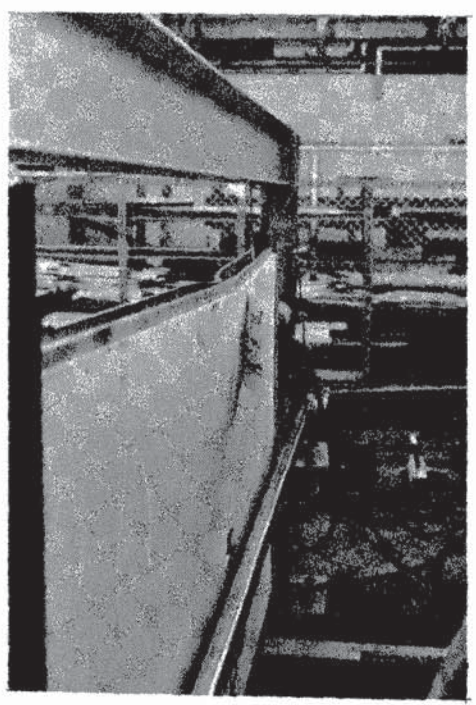
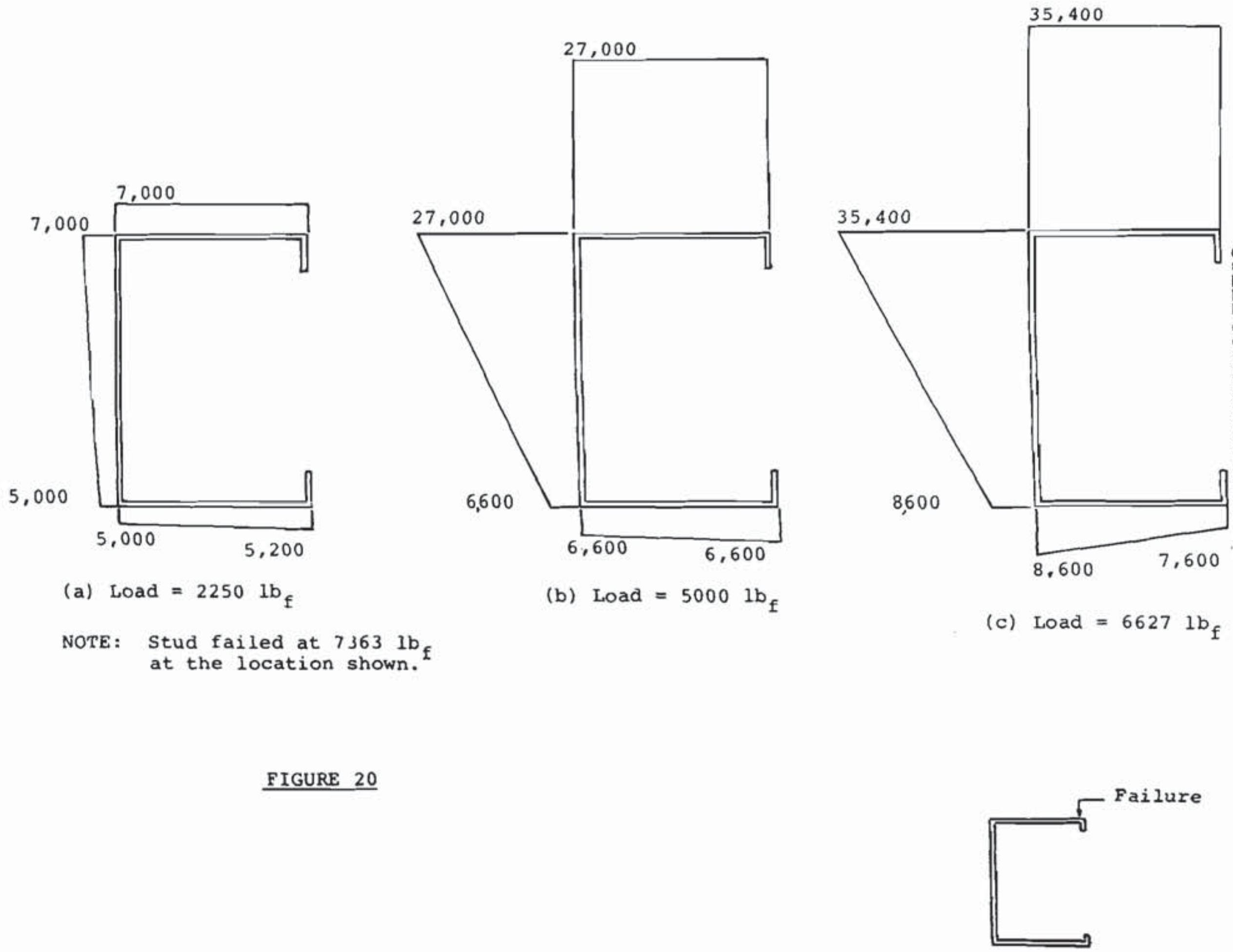


FIGURE 19



NOTE: Stud failed at 7363 lb_f at the location shown.

FIGURE 20

FIGURE 21

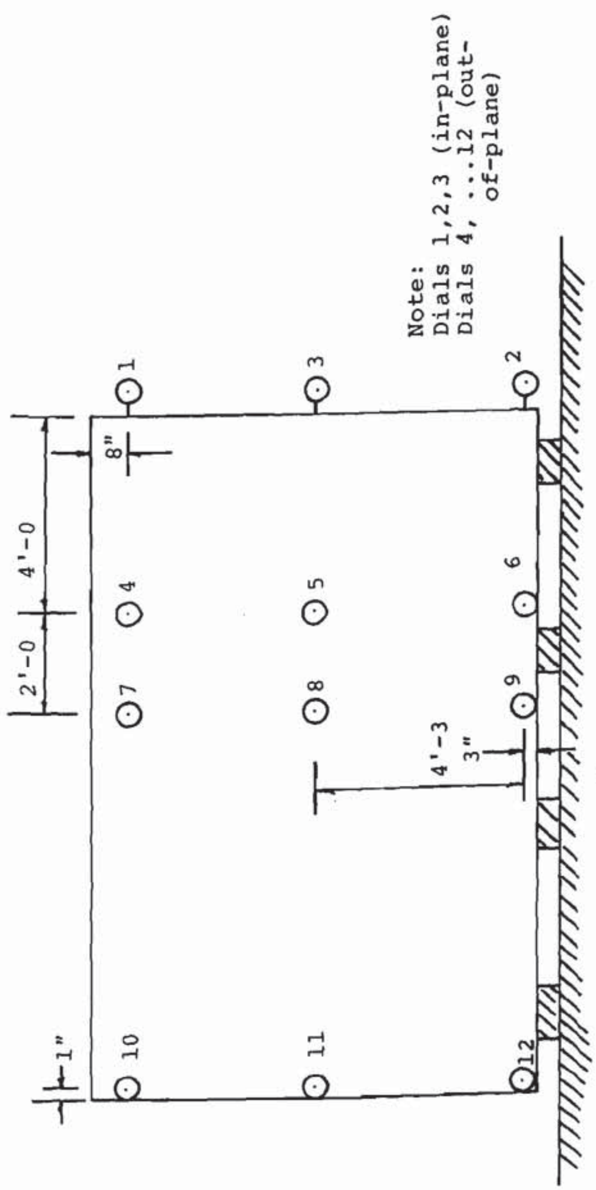
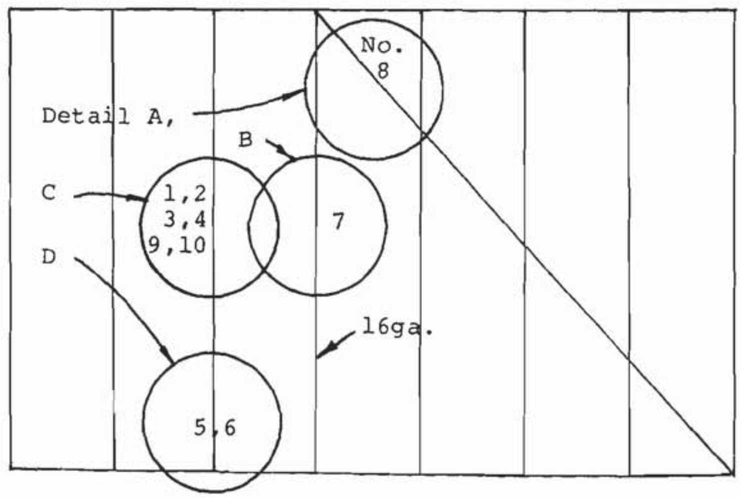
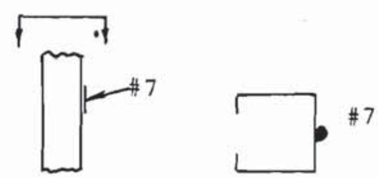

Note:
Dials 1,2,3 (in-plane)
Dials 4, ...12 (out-of-plane)
1
2
3
4
5
6
7
8
9
10
11
12
4'-0
2'-0
8"
1"
4'-3
3"
floor

FIGURE 22

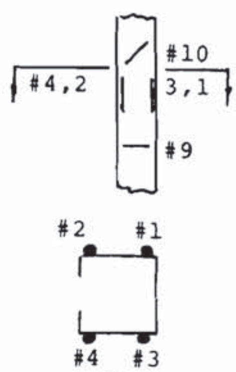


a) Gross Locations of Strain Gauges

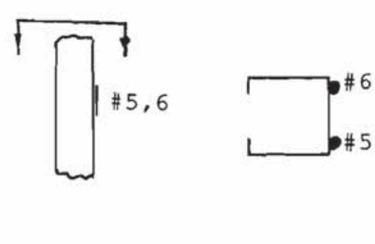
DETAIL A
(BRACING STRAP)



DETAIL B



DETAIL C



DETAIL D

FIGURE 23

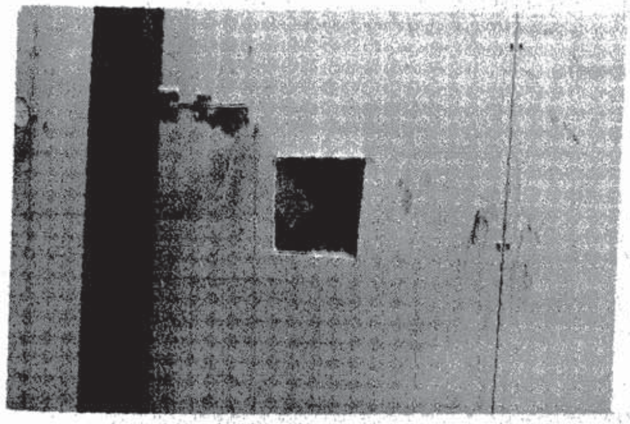


FIGURE 24

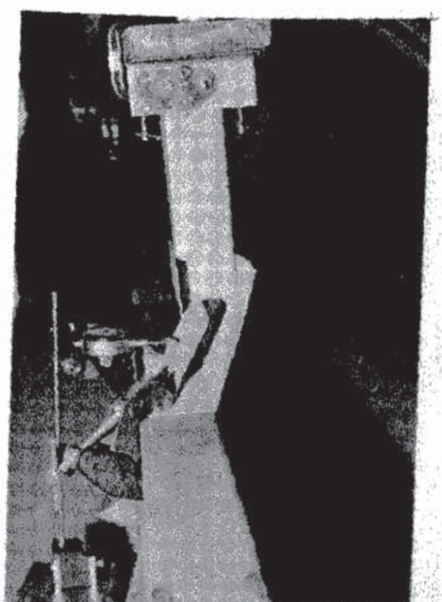


FIGURE 25

FIGURE 26

FIGURE 27

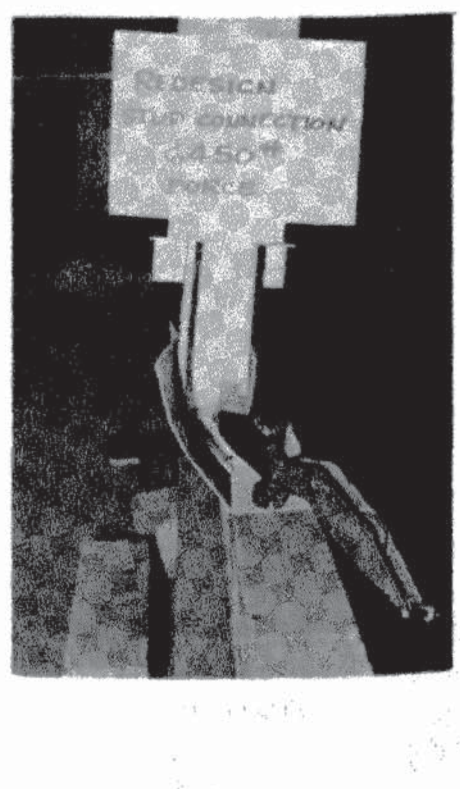


FIGURE 28

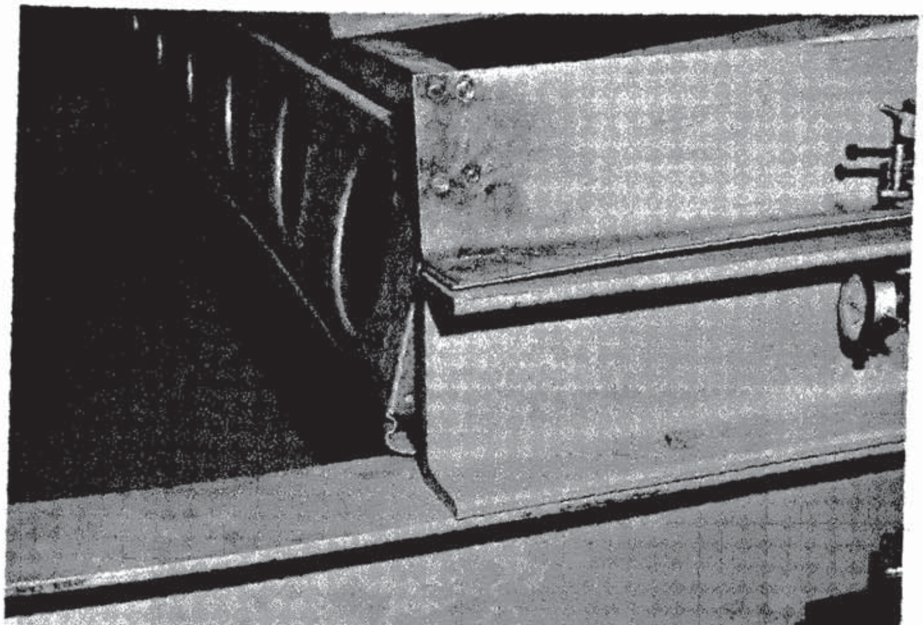


FIGURE 29

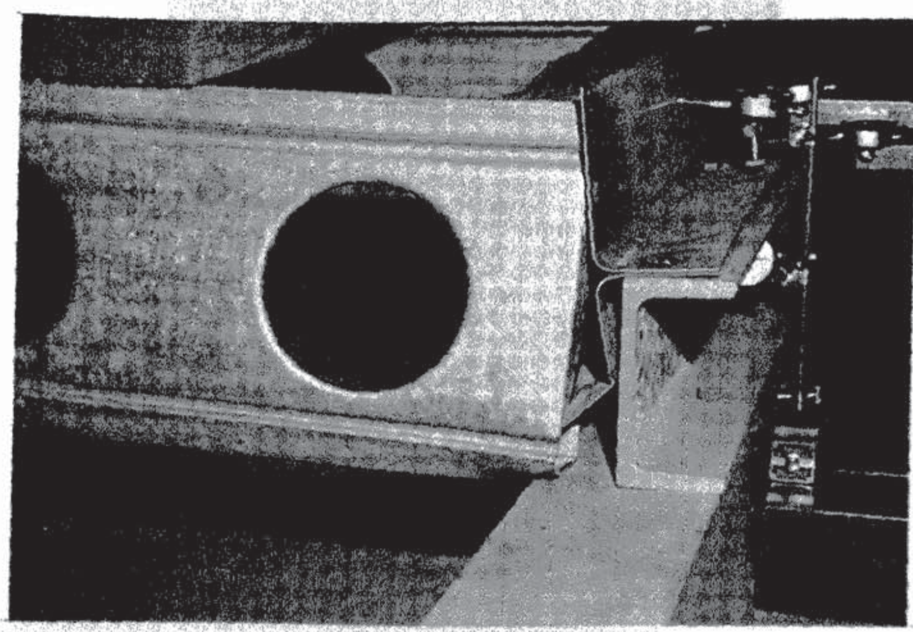


FIGURE 30

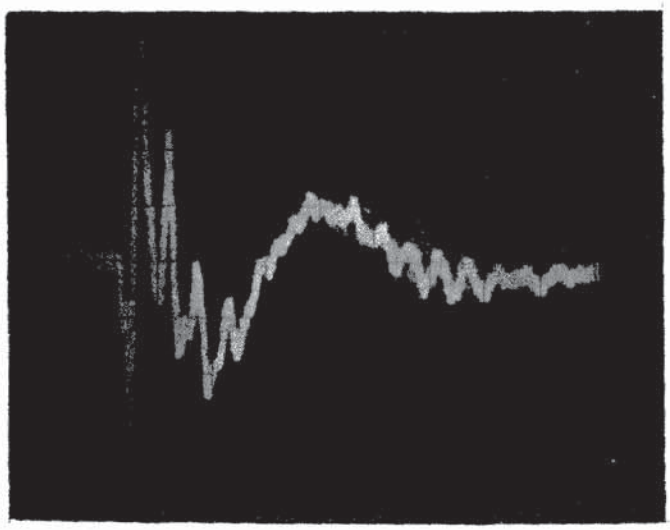


FIGURE 31

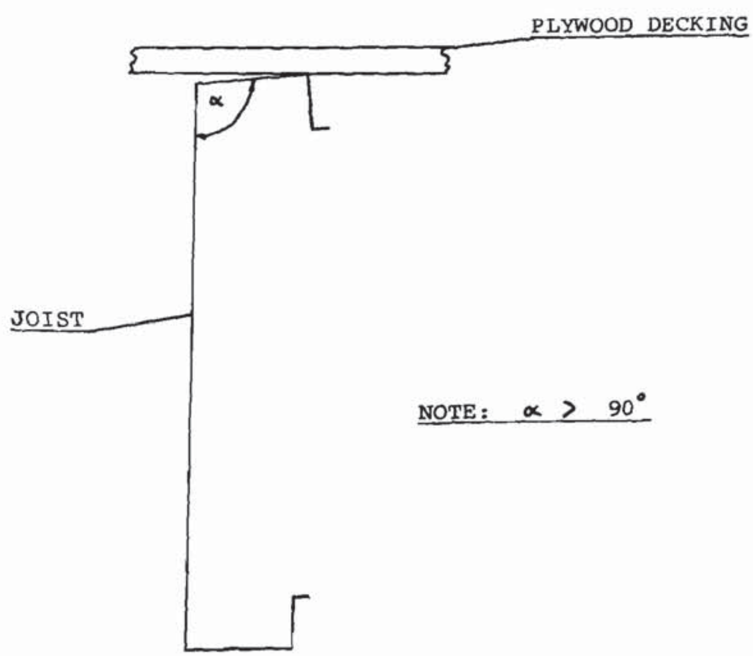


FIG. 32

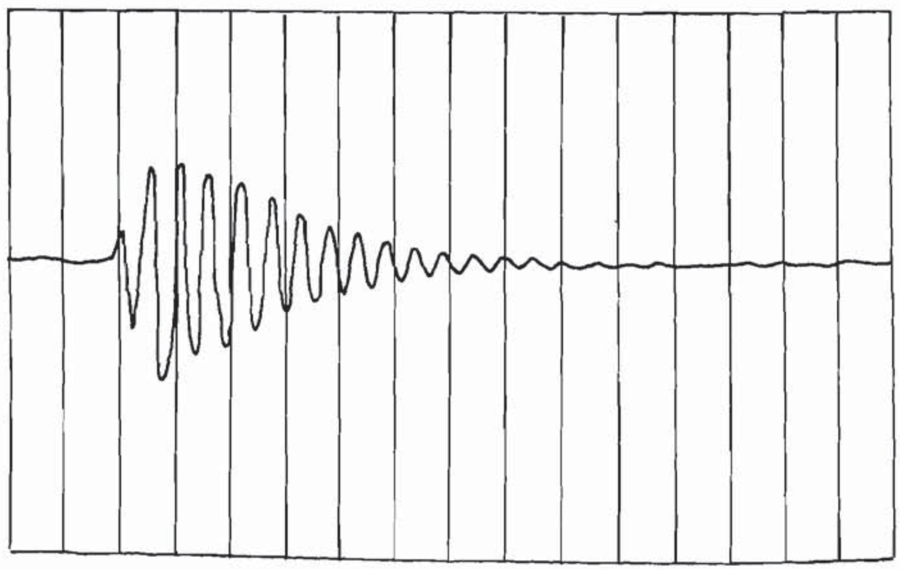


FIGURE 33

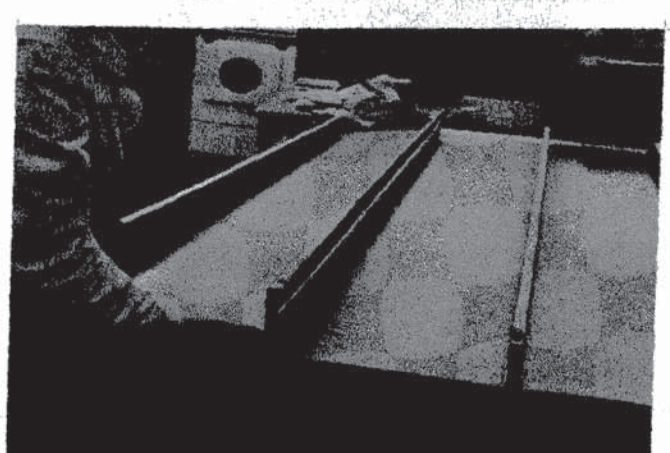
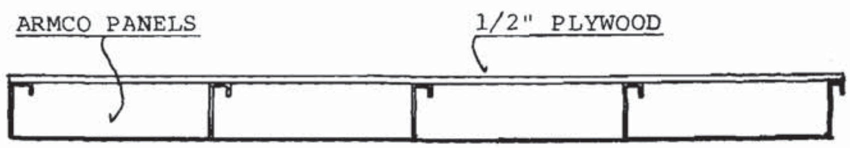
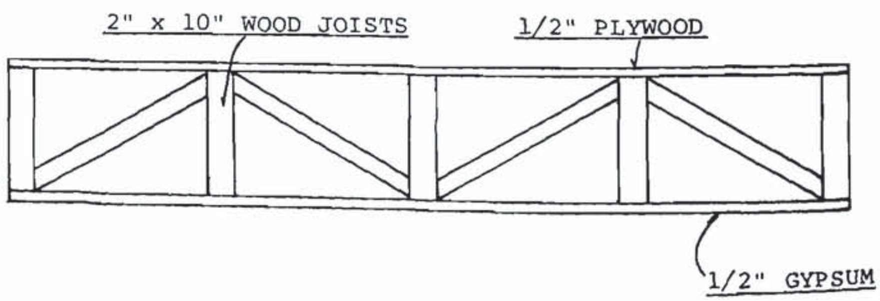


FIGURE 34



SECTION THRU 'ARMCO' DECK ASSY.

NOMINALLY 5'-4" x 12'-0"



SECTION THRU ALL-WOOD DECK ASSY.

NOMINALLY 5'-4" x 12'-0"

FIG. 35

FIGURE 36

	Wood Deck d.b."A"	Steel Deck d.b. "A"	Steel Deck c/w Fibreglas d.b."A"
Ambient Level	50	48	46
Walking on Deck	56 - 58	54 - 56	55 - 57
Walking on Carpet	53 - 55	49 - 51	51 - 53
Dropping Boot on Deck	77	74	72
Dropping Boot on Carpet	68	65	65

FIGURE 37